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by

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Interim Waste Storage for the Integral Fast Reactor Fuel Cycle Demonstration

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The Integral Fast Reactor (IFR), which Argonne National Laboratory is developing, is an innovative liquid metal breeder reactor that uses metallic fuel and has a close coupled fuel recovery process. A pyrochemical process is used to separate the fission products from the actinide elements. These actinides are used to make new fuel for the reactor. As part of the overall IFR development program, Argonne has refurbished an existing Fuel Cycle Facility at ANL-West and is installing new equipment to demonstrate the remote reprocessing and fabrication of fuel for the Experimental Breeder Reactor II (EBR-II). During this demonstration the wastes that are produced will be treated and packaged to produce waste forms that would be typical of future commercial operations. These future waste forms would, assuming Argonne development goals are fulfilled, be essentially free of long half-life transuranic isotopes. Promising early results indicate that actinide extraction processes can be developed to strip these isotopes from waste stream and return them to the IFR type reactors for fissioning.

The primary processing steps of the fuel cycle include assembly dismantling, element chopping, electrorefining, cathode processing, injection casting, pin processing, and element and assembly fabrication. The majority of the fission products are removed in three streams at the electrorefiner. Although the classifications of these streams are not specifically identified for a research and development program, in a commercial process these wastes would be classified as high level. In the demonstration facility, waste processing equipment will be installed about two years after fuel reprocessing begins when sufficient material has been accumulated to operate the equipment. This waste processing equipment includes actinide extraction equipment, metal waste form alloying and salt encapsulation process. For demonstration of safe waste handling and disposal, an interim storage strategy had to be developed for these materials. This storage strategy will allow for the orderly development and installation of new waste processing equipment.

The ANL-West site has two storage locations which are available. The FCF has ten storage pits inside the Air Cell and seventeen storage pits inside the Argon Cell. Both of these cells are shielded hot cell facilities and will house the processing equipment. Also, the ANL-W site has a facility for the storage of radioactive material called the Radioactive Scrap and Waste Facility (RSWF). This facility has 3.76 meter deep holes that are steel lined. Each of the holes can hold one standard waste container, with exterior dimensions of 0.31 meters diameter by 1.87 meters long.

The following design constraints were considered for the interim storage system: compatibility with existing facility waste handling systems, capability of remote operations and maintenance, storage of the materials in a retrievable form, passive cooling of containers under normal and potential accident conditions, no free liquids during storage, and compliance with all appropriate DOE orders and EPA regulations. The strategy was developed by defining waste characteristics, developing conceptual designs of storage containers, modeling the passive heat transfer capability for different modifications of existing storage pits in the Fuel Cycle Facility, and heat transfer modeling in the RSWF. After these analytical capabilities were developed, an interactive design approach was taken to optimize the different parts to create a flexible storage strategy that met the goals of the overall development program and all of the different design constraints.

The characteristics of the three electrorefiner streams included physical and chemical characteristics, estimated production quantities, heat generation rates and radiological properties. The physical and chemical characteristics were developed from thermodynamic data and results from laboratory and cold pilot plant testing. The waste quantities, which are very small due to the developmental nature of the program, were generated using conservative assumptions to bracket all operations. The heat generation characteristics were developed as a function of time so each individual process stream could be evaluated in detail at different storage times and with different operating strategies. Since each stream contains different chemical groups of fission products, the specific radiological characteristics were developed and adjusted so that important source terms for accident exposure analysis could be identified. These individual stream characteristics were used as the basis to evaluate the different design options.

Due to the high thermal power levels of these streams, the heat transfer characteristics of different storage cans were an important variable. Different can designs and sizes were investigated so that the number of storage locations and shipments could be minimized. The can designs included finned and non-finned designs, various diameters, different types of finishes and different materials of construction. Also, the heat transfer effects of placing cans inside other cans for multiple levels of confinement was considered.

Since these process streams have a high thermal power output per unit volume, various passive convective cooling options were investigated for temporary storage of cans in existing storage pits in the FCF. The convective cooling design uses an insulated chimney inside the storage pits that induces natural convection currents. The ambient temperature argon settles in the outside annulus between the pit liner, and the chimney than turns at the bottom of the pits and rises between the annular space between the cans and chimney. This system eliminates the need for an active cooling system which would need to be nuclear-safety grade. Different chimney designs were investigated to determine a configuration that would be compatible with different thermal loads, waste can designs and existing facility limitations.

Because the waste repository will not accept wastes until after 2020 and additional waste processing development is needed, a storage system was needed that would allow for storage and easy retrieval outside the FCF. The waste containers from the FCF will be remotely placed inside a second container so that a contamination free outer container can be handled outside of the facility. These two containers are placed into a shielded cask for transporting to the RSWF and both containers are placed in the hole. This system provides multiple levels of containment yet allows for the materials to be transferred and later retrieved while minimizing personnel radiation exposure.

For the high thermal content FCF wastes, heat transfer models of the RSWF were developed so that different storage strategies could be investigated to assure that the materials remained below their melting point and the heat was dissipated. The models included radiative heat transfer from the inner can to the outer can and from the outer can to the liner. The liner then conducts the heat axially and radially to the surrounding ground. By iterating the radiation and conduction portions until the heat transfer is balanced, the storage temperature of the inner can could be determined. The thermal models were used to evaluate different can designs, different waste types, hole spacing in the storage area, hole liner thickness and different ground boundary conditions.

Since the electrorefining process uses cadmium, the three waste streams will exceed the Extractive Procedure (EP) Toxicity test limits, and thus are considered to be mixed radioactive wastes. This category required the permitting of the RSWF as a RCRA storage facility.

After the analytical tools were developed, a waste handling strategy was developed for each individual waste stream. In general, the different RSWF strategies resulted in thermal limits between 200 -350 watts per hole with one standard waste can. For the FCF facility storage pits with natural convection cooling, standard waste cans could contain between 2000 - 2500 watts. To minimize the number of holes and transfer operations, several strategies were evaluated where the cans were stored in the FCF for various holding times. This additional holding time would allow for loading standard cans to higher wattage and allowing radioactive decay to lower the thermal power levels before transferring to RSWF. This strategy would minimize the number of cans and storage holes needed for interim storage of the materials.

Figure 1 shows the thermal characteristics of the three different electrorefiner streams as a function of time from reactor discharge. The electrorefiner salts, which are used as the electrolyte in electrochemical separation process, are removed from the electrorefiner to maintain the process levels. The cadmium stream is produced from the oxidizing agent which is added into the electrorefiner. The electrorefiner insolubles are material which are neither oxidized in the electrorefiner or soluble in the cadmium. All three streams are only removed on an intermittent basis and so their production can be considered as batch operations.

The electrorefiner salts, which contain primarily the alkaline metal and alkaline earth fission products, have an initial lower thermal loading than the other two and have very stable thermal output beyond one year after reactor discharge. Since the average age of the fission products in the salt will be approximately two years, temporary storage in the FCF storage pits will not significantly reduce the thermal loadings in cans. Therefore for this material, the cans were sized to enable direct transfer to RSWF. With this scenario, the RSWF thermal limit is the limiting criteria on number of cans and transfers required.

The electrorefiner cadmium stream contains primarily the rare earth fission products which have significant radioactive decay during the first seven years of storage as shown in Fig. 1. By using the convective cooling capability of the FCF storage pits, the container size for this material could be maximized; however, the material would have to be stored for approximately seven years before being transferred to RSWF. Although this strategy placed more requirements on the storage pits at the FCF, the number of transfers and handling operations was reduced by approximately an order of magnitude.

The electrorefiner insolubles which are removed after the shortest operating time have the shortest average radioactive half life, and thus the greatest reduction in their thermal power with time. The containers for these materials were designed for very high thermal power levels initially and storage in FCF storage pits. After three to four years of storage, these containers would be bundled together and transferred to the RSWF. The number of RSWF storage holes that are required for these materials is limited by the physical dimension imposed by the initial storage requirements rather than the RSWF thermal limits. However, three to four years of storage in the FCF storage pits reduces the number of containers and storage holes by a factor of approximately eight.

Besides reducing the number of containers and storage hole requirements, the FCF waste handling strategy is being implemented to develop detailed characterization of each individual waste stream, and methods are being designed for material retrieval remotely. This capability will allow new waste processing options to be developed and tested without requiring the need for new specialized facilities. The FCF waste strategy will be flexible enough to allow the demonstration of the fuel cycle process and its associated waste packaging and handling.

Figure 1: Thermal Power of Electrorefiner Wastes as a Function of Time